Review on Green synthetic approaches and applications of Zinc Oxide Nanoparticles

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***Abstract* - Nanomaterials are particles that have a nanoscale dimension. Nanoparticles are very small particles that have better catalytic reactivity, thermal conductivity, non-linear optical performance, and chemical stability because they have a lot of surface area to volume. There are three types of zinc oxide: wurtzite, zinc blende, and rocksalt. They are all inorganic materials that can be used to make electricity. There are many ways to make ZnO. These include sol–gel processing, homogeneous precipitation, mechanical milling, organic synthesis, microwave method, spray pyrolysis, thermal evaporation, and so on and so forth. Green synthesis processes have been used to make ZnO nanoparticles so that they don't harm the environment. This is how it works: ZnO has different chemical and physical properties. It can be used in many different fields. zinc oxide is used in many different things, from medicine to agriculture, paints to chemicals, and tyres to ceramics. Zinc oxide is important because it can be used in many different things. In the food, pharmaceutical, and cosmetic industries, the plant-based nanoparticle has a lot of potential. This makes it a big area of study.**

***Index Terms* - Zinc oxide nanoparticles, wurtzite, Spray pyrolysis, Green Synthesis.**

INTRODUCTION

Nanomaterials are particles having nanoscale dimension, and nanoparticles are very small sized particles with enhanced catalytic reactivity, thermal conductivity, non-linear optical performance and chemical steadiness owing to its large surface area to volume ratio (Tabrez et al. 2016). NPs have started being considered as nano antibiotics because of their antimicrobial activities (Sastry et al. 2003). Nanoparticles have been integrated into various industrial, health, food, feed, space, chemical, and cosmetics industry of consumers which calls for a green and environment-friendly approach to their synthesis (Rao et al. 2016).

DIFFERENT METHODS USED IN NANOPARTICLE SYNTHESIS

Nanoparticle synthesis is mediated by physical, chemical and green methods (Afifi et al. 2015; Chen et al. 2015; Vitosh et al. 1994). The physical method involves the use of costly equipment, high temperature and pressure (Chandrasekaran et al. 2016), large space area for setting up of machines. The chemical method involves the use of toxic chemicals which can prove to be hazardous for the environment and the person handling it. The literature states that some of the toxic chemicals that we use in physical and chemical methods may reside in the NPs formed which may prove hazardous in the field of their application in the medical field (Dhandapani et al. 2014). Thus, we needed an environment-friendly and cost- effective method for nanoparticle synthesis.

GREEN APPROACH

Biosynthesis of nanoparticles is an approach of synthesizing nanoparticles using microorganisms and plants having biomedical applications. This approach is an environment- friendly, cost effective, biocompatible, safe, green approach (Abdul et al. 2014). Green synthesis includes synthesis through plants, bacteria, fungi, algae etc. They allow large scale production of ZnO NPs free of additional impurities (Yuvakkumar et al. 2014). NPs synthesized from biomimetic approach show more catalytic activity and limit the use of expensive and toxic chemicals.

Plant parts like roots, leaves, stems, seeds, fruits have also been utilized for the NPs synthesis as their extract is rich in phytochemicals which act as both reducing and stabilization agent (Zong et al. 2014; Nachiyar et al. 2015; Ramesh et al. 2015; Xiao et al. 2016; Rajeshkumar et al. 2016; Nagajyothi et al. 2013; Gnanajobitha et al. 2013).

Zinc oxide is a semiconducting inorganic material with three different crystal structures: wurtzite, zinc blende, and rocksalt. At ambient conditions, the structure of wurtzite is thermodynamically stable, with every zinc atom being tetrahedrally coordinated with four oxygen atoms (Kulkarni et al. 2011).

With a wide band gap of 3.1–3.3 eV, (You et al. 1998) zinc oxide has great potential for application in many fields, such as biosensors, cosmetics, paints and coatings due to high UV protection, optics, and optoelectronics (Ishwarya et al. 2018), elimination of heavy metals from water (Stoimenov et al. 2002), and finally in medical fields such as nanodiagnostics, nanomedicine, gene delivery, drug delivery and antimicrobial activities (Roselli et al. 2003; Chellappa et al. 2018).

ZINC OXIDE STRUCTURE

Zinc oxide nanoparticles are categorized among the materials that have potential applications in many areas of nanotechnology (Hahn et al. 2011; Ding et al. 2013). ZnO possesses one-, two- and threedimensional structures. 1D structure involves tubes, needles, ribbons, nanorods helixes, belts, combs, wires, rings and springs (Frade et al. 2012). Twodimensional structure involves nanoplates and nanosheets that can give us zinc oxide. However, three-dimensional structure of zinc oxide includes snowflakes, coniferous, urchin-like flowers and dandelions. Zinc oxide gives greatly different particles among materials (Kołodziejczak-Radzimska et al. 2014). Also, zinc oxide in different shapes and structures can be seen in Figure 1(Xie et al. 2005; Haq et al. 2012) [28,29].

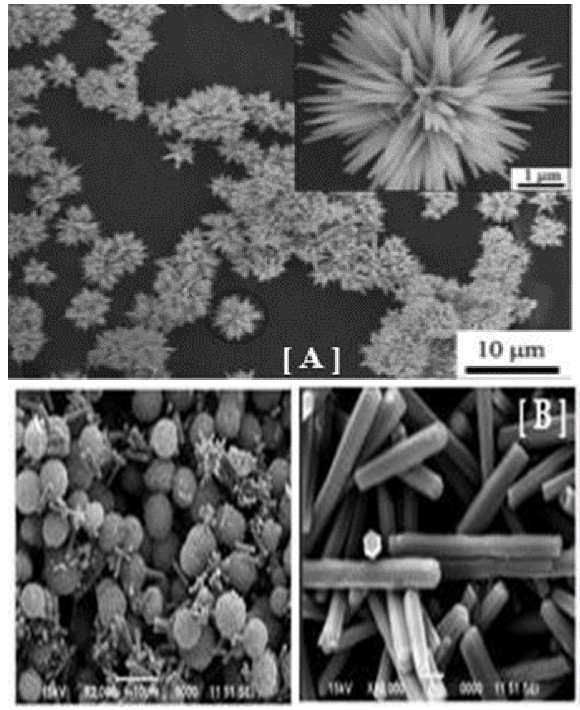

Figure 1: Different structures and shapes of zinc oxide. [A] : Flower Shape, [B]: Spherical and Rod

CRYSTAL STRUCTURE OF ZnO

Crystalline ZnO has a wurtzite (B4) crystal structure, having a hexagonal unit cell with two lattice parameters a and c. In this wurtzite hexagonal structure each anion is surrounded by four cations at the corners of the tetrahedron, which shows the tetrahedral coordination and hence exhibits the sp3 covalent bonding. The tetrahedral configuration of ZnO gives rise to a non-centro symmetric structure (Nomura et al. 2003; Sugihartono et al. 2018; Pearton et al. 2005) (Figure 2).

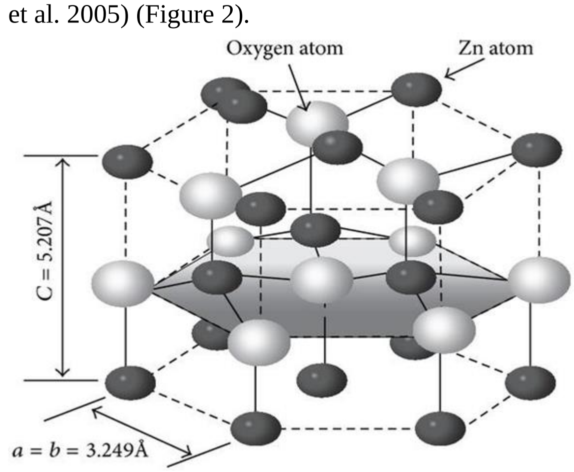

Figure 2: Tetrahedral structure of ZnO [33]

METHODS OF SYNTHESIS OF ZnO NPs

ZnO can be synthesized by many different methods, such as sol–gel processing, homogeneous precipitation, mechanical milling, organometallic synthesis, microwave method, spray pyrolysis, thermal evaporation (Sabir et la. 2014). However, these kinds of methods usually use organic solvents and toxic reducing agents, the majority of which are highly reactive and harmful to the environment. Therefore, in order to minimize the impact on the environment, green synthesis processes have been used to synthesize ZnO nanoparticles. Green synthesis is a method to produce nanoparticles using microorganisms and plants with biomedical applications. This method has many advantages, such as environmental friendliness, cost effectiveness, biocompatibility, and safety. Additionally, many studies have proved that ZnO NPs made using green synthesis processes have strong antibacterial properties.

GREEN SYNTHESIS OF ZnO NPs USING PLANT EXTRACT

Plant parts like leaf, stem, root, fruit, and seed have been used for ZnO NPs synthesis because of the exclusive phytochemicals that they produce. Using natural extracts of plant parts is a very ecofriendly, cheap process and it does not involve usage of any intermediate base groups. It takes very less time, does not involve usage of costly equipment and precursor and gives a highly pure and quantity enriched product free of impurities (Umavathi et al. 2021). Plants are most preferred source of NPs synthesis because they lead to large-scale production and production of stable, varied in shape and size NPs (Qu et al. 2011). Bio-reduction involves reducing metal ions or metal oxides to 0 valence metal NPs with the help of phytochemicals like polysaccharides, polyphenolic compounds, vitamins, amino acids, alkaloids, terpenoids secreted from the plant (Umavathi et al. 2021; Qu et al. 2011).

LITERATURE STUDY

Due to the increasing popularity of green methods, different works had been done to synthesize ZnO NPs using different sources like bacteria, fungus, algae, plants and others (Figure 3). A list of tables had been put to summarize the valuable work done in this field.

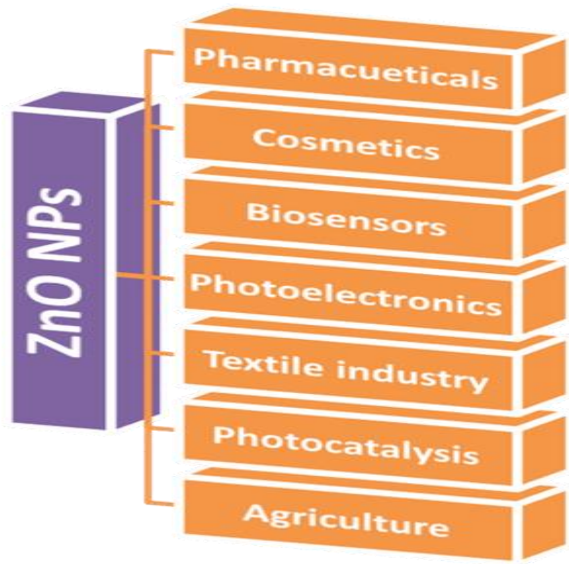

Figure 3: Chart showing various applications of ZnO NPs

Table 1: Synthesis of zinc oxide nanomaterials nanoparticles using various leaves extracts

S. No	Name of the extract	Shape	Size (nm)	Ref.
1	plant extract (Camellia sinensis)	spherical rods	10–20	Sendhil et al 2021
2	Aqueous Costusigneus Leaf Extract	spherical	31	Chinnasamy et al 2018
3	Aqueous Thymbra Spicata L. Leaf	irregular and almost spherical	6.5 - 7.5	Tuğba Gur et al 2022
4	Aqueous leaf extract of Ocimum tenuiflorum	Hexagonal	51	Hymavathi et al 2021
5	Aqueous leaf extract of Cinnamomum camphora(L.) Presl	spherical	13.5-21.5	Wenjia Zhu et al 2021
6	Aqueous leaves of Raphanus sativus var. Longipinnatus	partial crystal spherical shape	66.43	Umamaheswari et al 2021
7	Aqueous Cayratia pedata var. glabra plant	hexagonal	52.24	Jayachandran et al 2021
8	Aqueous Alhagi plant extract	crystalline nature with single phase	20.5-22.5	Alaa Falih et al 2021

9	Aqueous Ziziphus jujuba leaves extract	hexagonal wurtzite	15	Maymounah et al 2021
10	Aqueous Leea asiatica leaf	irregular and rod-like	218	Saheb Ali et al 2021
11	Aqueous talantia monophylla leaf extract	sphere	30	Vijayakumar et al 2018
12	Aqueous Neem plant (Azadirachta indicia) extract	non-spherical	20	Muhammad Farhan Sohail et al 2020
13	Juglans regia L. leaf extract)	spherical,flower	--	Elahe Darvishi et al 2019
14	Aqueous Deverra tortuosaplant extract	hexagonal	10-30	Selim et al 2020
15	Aqueous leaf extract of Abutilon indicum	spherical	10–30	Saraswathi et al 2021
16	Aqueous Kalanchoe pinnata leaf extract	spherical	24	Happy Agarwal et al 2019
17	Aqueous Moringa oleifera leaves	hexagonal	10 –25	Akintunde et al 2021
18	Aqueous Pseudomonas aeruginosa	--	--	Madhumita et al 2012
19	Aqueous Berberis aristata leaf extract	needle like	5-25	Harish Chandra et al 2021
20	Aqueous Aloe vera leaf extract	spherical	25 - 40	Gunalan Sangeetha et al 2021
21	Aqueous Eucalyptus globulus essential oil	rregular needle and spherical	24	Zahra Obeizi et al 2020
22	Aqueous extract of Phoenix roebelenii leaves	Spherical	8 – 25	Thana Shuga et al 2022
23	Aqueous Punica granatum leaf extract	spherical	10 - 30	Singh et al 2019
24	Mussaenda frondosa L	agglomerated exagonal structures	5 – 20	Jayappa et al 2020

Table -2 : Synthesis of zinc oxide nanomaterials nanoparticles using various parts of plant extracts

S. No.	Name of the Extract	Shape	Size(nm)	Ref.
1	Fruit Extract of *Amomum longiligulare*	Tetrameric strctured	50	Ying Chun et al 2020
2	Amygdalus scoparia stem bark extract	spherical	29	Fatemeh et al 2021
3	Flaxseed (*Linnum usitatissimum*) Mucilage	sheet-like	75	Seyyed Mohammad et al 2019
4	*Moringa Oleifera* Seed	*Spherical shape*	--	Rajeswari et al 2019
5	*Scutellaria baicalensis* (*S.baicalensis*) root extract	sphere-like structure	50	Ling Chen et al 2019
6	Fruit extract of *Viburnumopulus* L	--	14.88 - 9.23	Taşdemir et al 2021
7	*Ulva lactuca* seaweed extract	triangles, hexagons, rods and rectangles	10–50	Ramachandran et al 2018
8	*Ricinus communis* plant seed extract	non-uniform	10-30	Shobha et al 2019
9	Panos extract are roots of *Panax ginseng*, Stem portions of *Acanthopanax senticosus*, *Kalopanax septemlobus* and *Dendropanax morbifera*	leafy flower like structure	120	Kaliraj et al 2019
10	Immature Fruits of *Rubus coreanu*	crystalline in nature	23.16	Esrat Jahan Rupa et al2018
11	uphorbia Jatropa plant latex	hexagonal	50–200	Geetha et al 2016

Table-3: Applications of zinc oxide nanomaterials for the removal of several toxic elements and dyes

S.No	Plant extract	application	Ref.
1	plant extract (*Camellia sinensis*	methyl orange (MO) dye and degradation of 80% antibacterial activities	Sendhil et al 2021
2	Aqueous Costusigneus Leaf Extract	---	Chinnasamy et al 2018
3	Aqueous *Thymbra Spicata L.* Leaf	antimicrobial, antioxidant and effective agent protecting cells against DNA damage	Tuğba Gur et al 2022
4	Anoectochilus elatus	antimicrobial, anti-inflammatory, and potential antioxidant activities	Natesan Vijayakumar et al 2021

5	Leaf extract of *Cinnamomum camphora* (L.) Presl	antifungal activity	Wenjia Zhu et al 2021
6	Leaves of *Raphanus sativus var. Longipinnatus*	Anticancer activity	Umamaheswari et al 2021
7	Cayratia pedata var. glabra plant	Immobilization of enzyme	Ashwini Jayachandran et al 2021
8	*Ziziphus jujuba* leaves extract	*removal methyl orange (MO), and methylene blue and Pb(II)*	Maymounah et al 2021
9	Fruit Extract of *Amomum longiligulare*	photodegradation of methylene blue 66% and malachite green dyes 38.1%	Ying Chun et al 2020
10	Leea asiatica leaf	antioxidant test Anticancer	Saheb Ali et al 2021
11	Amygdalus scoparia stem bark extract	antibacterial, antifungal, anticancer, and anti- diabetic agents	Fatemeh et al 2021
12	*Syzygium cumini* (Java plum) aqueous leaf extract	Antioxidant test Anti-cancer, Nanonutrients activity	Manikandan et al 2021
13	Flax seed Mucilage	removal of methylene blue 80%	Seyyed Mohammad et al 2019
14	*Atalantia monophylla* leaf extract	antibacterial, antifungal	Vijayakumar et al 2018
15	Neem plant (*Azadirachta indicia*)	anti-oxidant, enzyme inhibition, and antimicrobial	Muhammad Farhan Sohail et al 2020
16	Juglans regia L. leaf extract	Cytotoxicity, Anti-bacterial	Elahe Darvishi et al 2019
17	Cayratia pedata. leaf	Enzyme immobilization	Selim et al 2020
18	*Scutellaria baicalensis* (*S.baicalensis*) root extract	Photocatalytic degradation of methylene blue 98.6%	Ling Chen et al 2019
19	fruit extract of *Viburnum opulus* L	Antibacterial impedance analysis	Taşdemir et al 2021
20	leaf extract of *Abutilon indicum*	Antibacterial	Saraswathi et al 2021
21	*Kalanchoe pinnata* leaf extract	Anti-inflammatory potential Enzyme-linked immunosorbent anti-oxidant	Happy Agarwal et al 2019
22	*Ulva lactuca* seaweed extract	Photocatalytic Methylene blue 90%, antibiofilm and larvicidal activity	Ramachandran et al 2018
23	*Moringa oleifera* leaves	anti-oxidant	Akintunde et al 2021
24	Pseudomonas aeruginosa	antimicrobial	Madhumita et al 2012
25	Berberis aristata leaf extract	anti-oxidant, Antibacterial	Harish Chandra et al 2021
26	*Eucalyptus globulus* essential oil	Antimicrobial and anti-biofilm activities	Zahra Obeizi et al 2020
27	*Ricinus communis* plant seed extract	Antioxidant, antifungal and anticancer activity	Shobha et al 2019
28	extract from four panax plants such as Panax ginseng, Acanthopanax senticosus, *Kalopanax septemlobus* and Dendropanax morbifera)	methylene blue (MB), Eosin Y (EY) and Malachite green>99%	Kaliraj et al 2019
29	extract of Phoenix roebelenii leaves	Antioxidant, Photocatalytic Methylene blue	Thana Shuga et al 2022
30	Immature Fruits of *Rubus coreanu*	degradation of Industrial Dye	Esrat Jahan Rupa et al 2018
31	Ethanolic extract of Camellia sinensis L	drug delivery system on MCF-7	Maedeh Akbarian et al 2020

APPLICATIONS OF ZnO NPs

ZnO has different chemical and physical properties. It can be used in numerous fields. Zinc oxide is important in a wide range of applications, from medicine to agriculture, from paints to chemicals and from tires to ceramics.

AGRICULTURAL APPLICATIONS

ZnO NPs have potential to enhance the growth of food crops. Seeds fixed by various ZnO NP concentrations improved seed propagation, seed strength and plant growth. ZnO NPs showed to be active in growing roots stems and seeds (Prasad et al. 2012). Importance of zinc oxide NPs in biotechnology area was investigated by Paul and Ban (Paul et al. 2014). They observed the effect of chemically prepared ZnO NPs on the biological system. Zinc oxide is also used at different concentrations from (Streptococcus pneumonia, Bacillus subtitles, E.Coli and Pseudomonas aeruginosa). A quick rise of enzymatic activity was found through high concentrations of zinc oxide (Paul et al. 2014). A summary of ZnO uses in different fields is shown in Figure 4 (Kołodziejczak-Radzimska et al. 2014).

MEDICINAL APPLICATIONS

Zinc oxide NPs have certain properties that make them appropriate for applications associated with the central nervous system (CNS) and possibly with the improvement procedures of disease treatment over (mediating neuronal excitability) or (even the release of neurotransmitters). Several types of research have shown that zinc oxide influenced unalike tissues, cells or functions, as well as neural tissue engineering and biocompatibility (Osmond et al. 2010).

NEGATIVE OR TOXIC IMPACTS OF ZnO NPs

Although the ZnO NPs have great commercial importance and are present in various commercial products there is clearly a growing public concern to know about the toxicological and environmental effects of ZnO NPs. Unfortunately, toxicological studies carried out on zinc oxide nanoparticles in the last ten years show that ZnO NPs have potential health as well as environmental risks. ZnO NPs can impose serious toxicity to bacteria, *Daphnia magna*, freshwater microalga, mice, and even human cells (Sharma et al. 2009; Brayner et al. 2006; Franklin et al. 2007; Heinlaan et al. 2008; Wang et al. 2008).

CONCLUSION

Biosynthesis of nanoparticles using eco-friendly approach has been the area of focused research in the last decade. Green sources act as both stabilizing and reducing agent for the synthesis of shape and size-controlled nanoparticles. Future prospect of plant mediated nanoparticle synthesis includes an extension of laboratory-based work to industrial scale, elucidation of phytochemicals involved in the synthesis of nanoparticles using bioinformatics tools and deriving the exact mechanism involved in inhibition of pathogenic bacteria. The plant-based nanoparticle can have huge application in the field of food, pharmaceutical, and cosmetic industries and thus become a major area of research.

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Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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